Sept. 29, 1970 G. CECCHINI 3,531,712

CURRENT STORAGE D-C VOLTAGE CONVERTER

Original Filed July 28, 1967 4 Sheets--Sheet 1

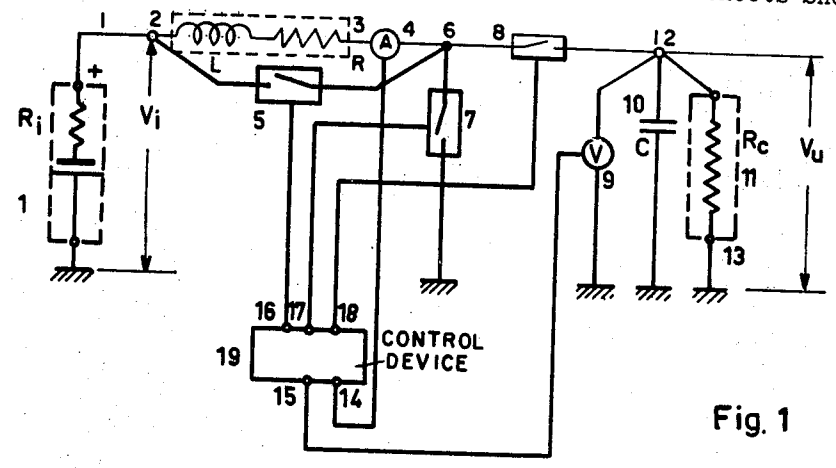


Fig. 1

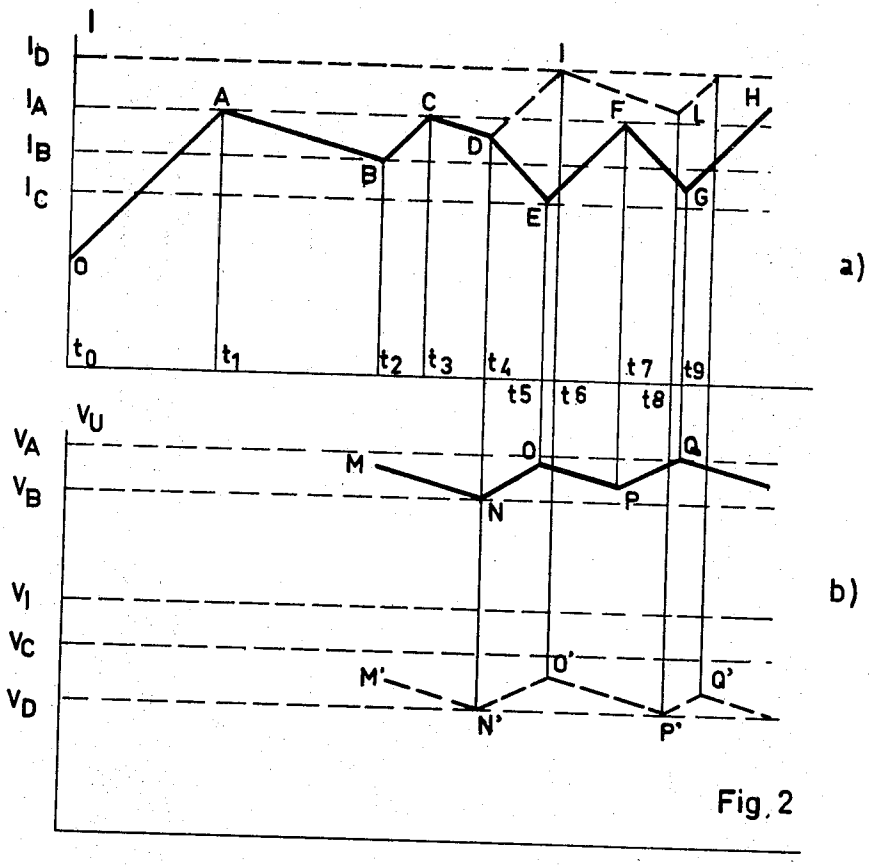


Fig. 2

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CURRENT STORAGE D-C VOLTAGE CONVERTER

Original Filed July 28, 1967 4 Sheets-Sheet 2

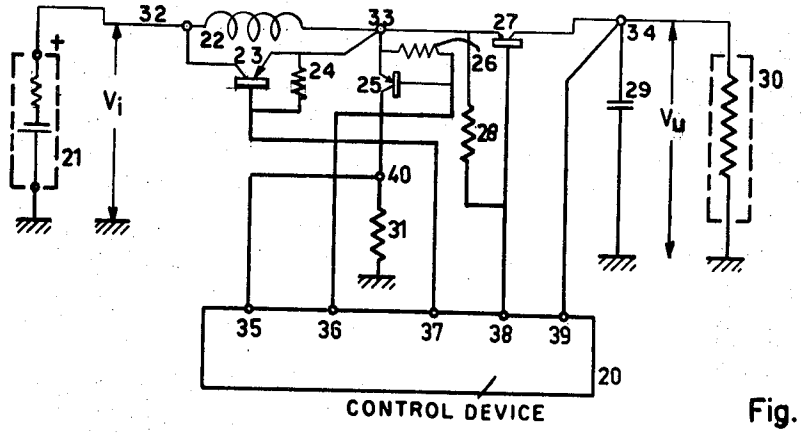


Fig. 3

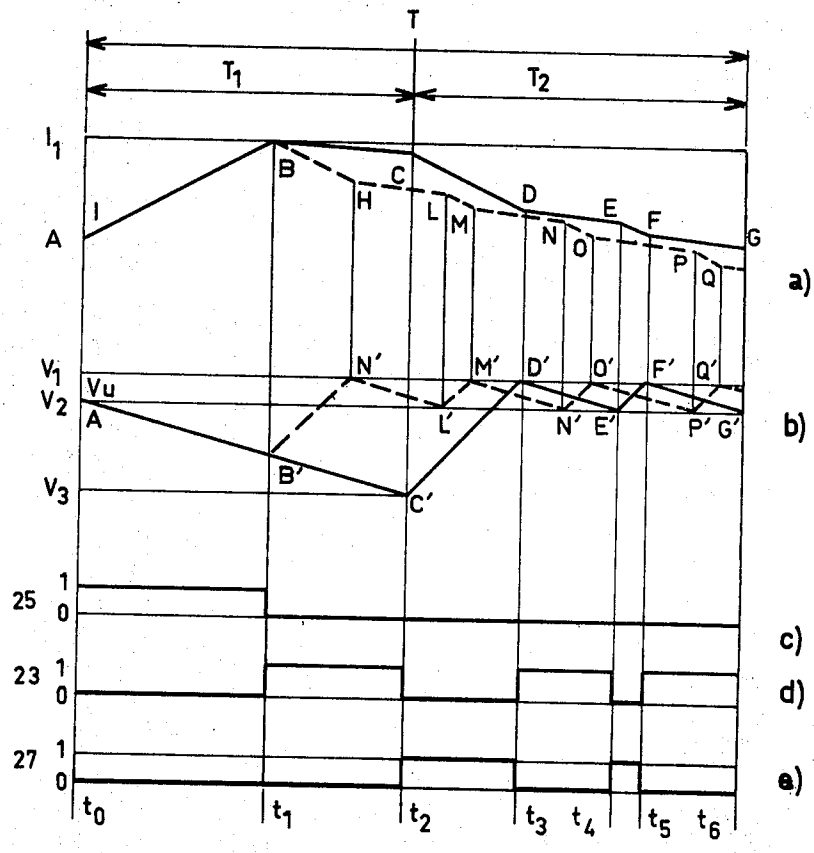


Fig. 4

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CURRENT STORAGE D-C VOLTAGE CONVERTER

Original Filed July 28, 1967 4 Sheets-Sheet 3

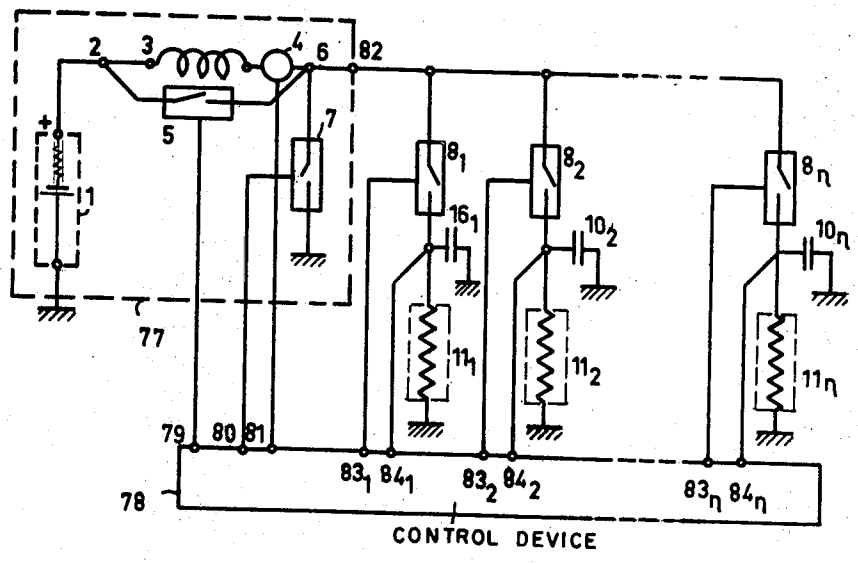


Fig. 5

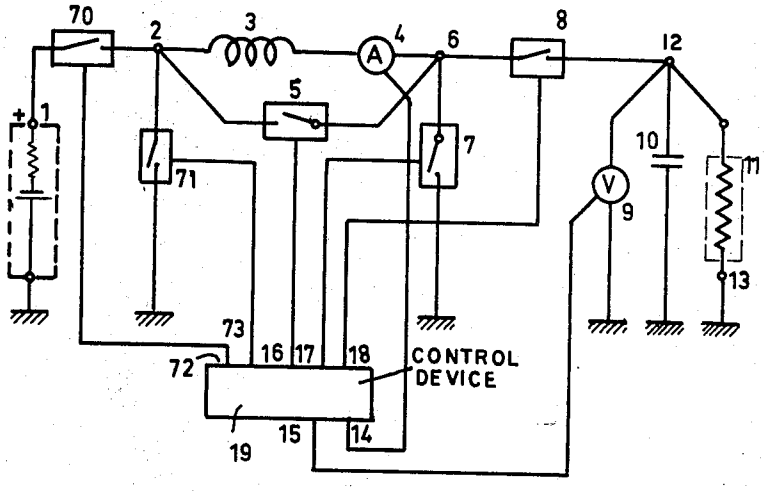


Fig.6

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CURRENT STORAGE D-C VOLTAGE CONVERTER

Original Filed July 28, 1967 4 Sheets-Sheet 4

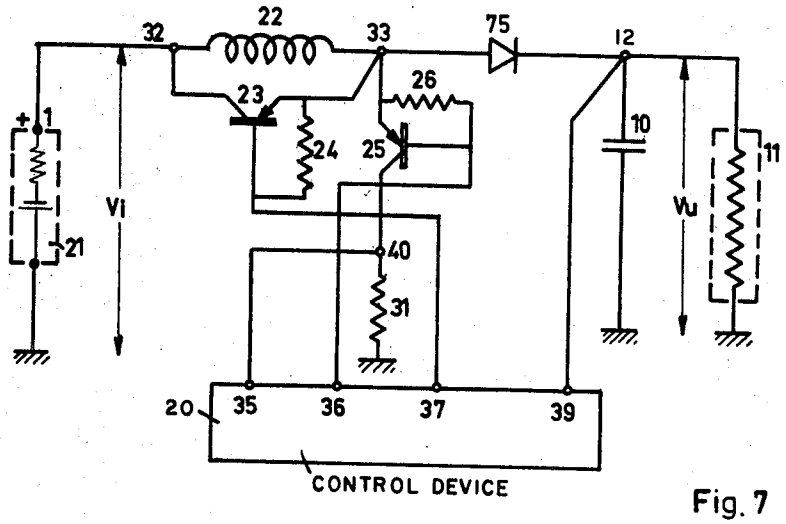


Fig. 7

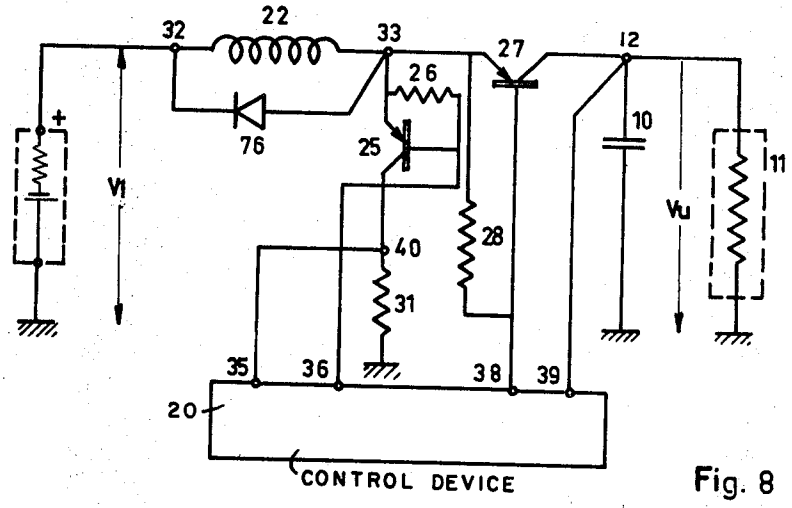


Fig. 8

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United States Patent Office 3,531,712 Patented Sept. 29, 1970

3,531,712

CURRENT STORAGE D-C VOLTAGE CONVERTER

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Continuation of application Ser. No. 656,793, July 28, 1967. This application June 6, 1969, Ser. No. 833,884
Claims priority, application Italy, July 30, 1966, 17,737/66, Patent 774,432
Int. Cl. G05f 1/56
U.S. Cl. 323—4 12 Claims

ABSTRACT OF THE DISCLOSURE

A direct current voltage converter wherein voltage stabilization is effected by storage of current in an inductive device, said current being supplied to a load subject to the sensing of voltage and current requirements of the load and through the operation of appropriate switches to make such stored current available at the appropriate time.

This application is a continuation of U.S. patent application 656,793, filed July 28, 1967.

The present invention relates to direct-current voltage converters, that is, to devices which operate from an unregulated source of direct current to produce a direct-current output at a different voltage wherein the output voltage is, in general, stabilized and regulated between definite limits.

In prior art devices of this kind, the problem of converting the voltage of a direct current source from a given value to a different one, is generally solved by transforming the direct-current input to the device into a pulsing or alternating current by means of a vibrator or an inverter, or a similar device, and by feeding this pulsing or alternating current into the primary winding of a transformer, thus obtaining as an output from the secondary winding, an alternating current having a predetermined voltage. This current is rectified and smoothed, to produce a direct current output at the required voltage. A stabilizing arrangement may be introduced into the converter, by means of a feedback device responsive to the difference between the effective and the required output voltage.

In such apparatus, the maximum voltage value of the output current is determined by the turn ratio between primary and secondary winding of the transformer, and lower voltage values may be obtained by energy dissipating means, therefore the stabilized output voltage must be predetermined by the designer and may change only between very restricted limits.

Moreover, the use of a transformer is a cause of lower efficiency and of noise, due to the hysteresis loss in the iron core, which is subject to an alternating flux.

In a different type of regulated converter, which does not use transformers, the output voltage is necessarily lower or, at most, equal to the voltage of the feeding direct current source. There is a substantial limitation to the values of the output voltage, and remarkable power dissipation may take place.

The present invention obviates the above referred to inconvenience, its object being to provide, without the use of transformers, a direct current voltage converter wherein the output voltage is wholly independent, within large limits, of the voltage of the input D-C source. In particular, the output voltage may be several times higher than the input voltage.

The converter, according to the invention, comprises an inductor, through which a substantially constant current is caused to flow by means of a control device which,

in response to data delivered by convenient measuring arrangements, controls a multiplicity of switches, thereby causing, in differently interlaced time intervals, the selective connection of the inductor either to the stabilized current source alone; to the stabilized current source and the load circuit; to the load circuit alone; or the short-circuiting of the said inductor, which thereby acts as a current-storage device.

When the inductor is connected to the load, it acts as an almost ideal current generator, therefore feeding the load circuit at a voltage, which depends only on the output circuit characteristics, and is independent of the direct-current input source voltage.

Therefore, the converter, according to the invention, provides the conversion of the voltage of an unstabilized D-C source to the value required by the load, without the use of transformers, and without ever inverting or interrupting the current in the inductor.

In addition, the device, according to the invention, may be used to generate a multiplicity of voltages of different values applied to different loads, through the use of a single non-stabilized power source and a single inductor.

These and other features and advantages of the invention will appear more clearly from the detailed description of an illustrative embodiment thereof, taken in conjunction with the accompanying drawings, in which:

FIG. 1 represents a circuit diagram of the device.

FIG. 2*a* and FIG. 2*b* are graphs representing the currents and voltages in different operating conditions.

FIG. 3 represents a simplified circuit diagram of a particular embodiment of the invention.

FIG. 4*a* and FIG. 4*b* represent the currents and voltages in said particular embodiment.

FIGS. 4*c*, 4*d*, 4*e* are the diagrams representing the ON and OFF conditions of the switches in the same embodiment.

FIG. 5 represents a circuit diagram having a multiplicity of loads.

FIG. 6 is a circuit diagram of another embodiment of the invention.

FIG. 7 and FIG. 8 are circuit diagrams of two simplified forms of the invention.

In FIG. 1 the circuit diagram of the device is shown in its basic form. The direct-current non-stabilized power source **1**, having the internal resistance R_i, delivers to input terminal **2**, a direct voltage of value V_i with respect to ground.

Inductor **3** is connected to input terminal **2** and a current measuring device **4**, having a very small resistance, is serially connected to inductor **3**. This current measuring device **4**, delivers an information signal related to the current value, to input **14** of the control device **19**. The inductance value L of inductor **3** is conveniently large, and its resistance value R, including the resistance value of the current measuring device **4**, is small. A switch **5**, controlled by an output **16** of the control device, is connected between input terminal **2** and output terminal **6**. When said switch is closed, inductor **3** is short-circuited.

A second switch **7**, controlled by an output **17** of the control device **19** may connect the output **6** to earth. In this condition a circuit comprising the power source **1**, inductor **3**, current measuring device **4**, and switch **7**, is completed.

A third switch **8** is controlled by output **18** of the control device **19**. When switch **8** is closed, output terminal **6** is connected to load terminal **12**, to which following circuits are parallel connected: the load **11**, which is assumed to be substantially resistive having a resistance R_o, a capacitor **10** of capacity C; a high impedance voltage measuring device **9**, which is capable of measuring the output voltage V_u and which sends a corresponding information signal to input **15** of control device **19**.

It is assumed that the switches **5**, **7** and **8** are operated instantaneously in response to the device **19** and that the switches, when closed, show practically no resistance, and, when open, show no conductance, within the range of current and voltage values to which they are subjected.

A possible operating sequence for the device of FIG. 1 is described, hereinafter, with reference to FIGS. 2*a* and 2*b*, which show the variation of the current I in the inductor and that of voltage V_u across the load.

It is assumed that, at the initial time t_0, switch **7** is closed, switches **5** and **8** being open. A circuit is completed, from the positive terminal **2** of the source **1**, having the internal resistance R_1, through inductor **3**, and current measuring device **4**, having a combined resistance R and an inductance L, and the closed switch **7**, to ground. The current I in such a circuit increases according to an exponential law having a high time constant $L/R+R_1$. If the time interval considered is sufficiently small with respect to said time constant, the current increase with time may be considered to be linear, as represented by line OA in FIG. 2*a*. When the current reaches a predetermined upper limit value I_A at time t_1, the control device **19** closes switch **5** and opens switch **7**. Inductor **3** is therefore short-circuited by the switch **5**. The current in the inductor will decrease according to a very large time constant L/R, as represented by line AB.

When the decreasing current has reached a lower limit value I_B, at time t_2 switch **7** closes and switch **5** opens, thereby restoring the conditions existing in the time interval t_0–t_1. The current will then increase until it reaches the upper limit value I_A, at time t_3, switch **5** closes and switch **7** opens. Therefore, through the operation of control device **19**, a unidirectional current, whose value is confined between limits I_A and I_B, is maintained in inductor **3**. As the difference between the exterior limits may be made very small, a direct current having a substantially constant value $I_m=(I_A+I_B)/2$ flows through the inductor.

The circuit components are so designed, that the value I_m is substantially higher than the value of the current drawn by the load. The inductor L operates as a current storage device, periodically reloaded by source **1**. Energy dissipation is negligible as resistance R_1 and R are very small.

We now consider the external load **11** fed from terminal **12** to which the capacitor **10** is also connected. The capacitor **10** is charged at a variable voltage V_u, which must be maintained between two predetermined limits V_A and V_B.

It is assumed that said limits are both higher than the input voltage V_1 and differ only by a small value, such that a voltage, $V_m=(V_A+V_B)/2$, approximately constant, is present at the output terminal **12**.

The current drawn by the load **11** discharges condenser **10**, in such a way, that the output voltage V_u decreases according to a law which may be represented by line MN in FIG. 2*b*. The instantaneous values of said voltage are measured by voltage measuring device **9** and the corresponding information signals are sent to input **15** of the control device **19**. When the voltage V_u reaches the lower limit V_B at time t_4, the control device closes switch **8** and opens switch **7** or switch **5**, according to which one was previously closed (in case under consideration, switch **5**).

Thus a circuit is completed, from output terminal **2** of the power source **1**, through inductor **3**, current measuring device **4**, switch **8** and load **11**, to the ground or earth.

In that part of the circuit of FIG. 1 which is between terminal **2** and terminal **12**, a positive voltage difference $\Delta V=V_1-V_u$ is present, that is directed in the same sense of the current under conditions of $V_1>V_u$, negative in the opposite case. In this part of circuit the inductive E.M.F. LdI/dt is active. At time t_4, when switch **8** is closed, disregarding the resistance R, it is

$$LdI/dt=\Delta V$$

The derivative dI/dt of the current has the same sign as ΔV: therefore the current will increase or decrease according to whether the output voltage is lower or higher than the input voltage. In any case, at least for a finite time interval, the current will continue to flow in the same direction as before, therefore charging capacitor **10** and causing voltage V_u to increase.

If, as assumed, the output voltage V_u is higher than V_1, ΔV is negative and the current will decrease as indicated by the solid line DE in FIG. 2*a*. Correspondingly, the output voltage V_u will increase as shown by the solid line NO.

It may happen, as shown by the figure, that at time t_5, before the voltage V_u reaches the upper limit V_A, the current reaches a second lower limit I_C, below which it is not advisable to let it decrease. In such a case the control device **19** closes switch **7** and opens switch **8**, thereby restoring the conditions for increasing the inductor current, and the current increases as shown by EF till time t_7, at which time it reaches the upper limit I_A, while the voltage decreases along OP. At time t_7 switch **8** closes and switch **7** opens, the current charges the condenser and causes its voltage to increase till it reaches the upper limit V_A (line PQ). In this condition switch **8** opens and either switch **7** or switch **5** close, depending on whether the current value in the inductor is lower or higher than value I_B.

In the event the output value V_u is lower than input value V_1, the voltage difference V is positive, and, therefore, dI/dt is positive.

As switch **8** closes the current increases, as shown by the dashed line DI of FIG. 2*a*.

The dashed line in the lower part of FIG. 2*b* shows the output voltage variation in the event the voltage must be confined between limits V_C and V_D; both lower than input voltage V_1.

If at time t_4, the output voltage decreasing along line M'M', reaches the lower limit V_D, the control device closes switch **8** and opens switch **7** or **5**. From this time on, as heretofore shown, the inductor current will increase along the dashed line DI, and correspondingly voltage V_u will increase as shown by line N'O'.

It may happen that, before the voltage V_u has reached the upper limit V_c, the inductor current reaches a second upper limit I_D over which it is not advisable to permit it to increase. In this event the control device closes switch **5** and opens switch **8**. The current will decrease along line IL till voltage V_u has reached the lower limit V_D at time t_8 (line O'P'). The process is repeated, and the output voltage is always confined between limits V_C and V_D.

By a proper choice of the characteristics of inductor **3** and capacitor **10**, considering the current drawn by the load **11**, and the current which may be delivered by the source **1**, it is possible to provide that the energy, delivered by the source to inductor **3** during the intervals when switch **7** is closed, is at least sufficient to compensate for the energy delivered by inductor **3** to condenser **10** during the intervals when switch **8** is closed.

The operation of the device according to the invention may be more concisely described considering that, when switch **8** is closed and the other switches are open, the inductor acts, at least for a finite interval of time, as an ideal current generator, and is therefore capable of delivering to the load a determined current, whatever may be the feeding voltage to the load.

It is clear that the operating pattern described may be changed in many ways, either by connection of the switches and measuring devices in a different configuration or with respect to the succession of opening and closing operations of the switches and the operative logic of the control device.

In particular, it may be convenient to introduce a clocking device, so that the closing and opening operations of the different switches do not depend exclusively upon the reaching of predetermined limit values for the voltage and the current, but rather that they, at least partially follow

a predetermined temporal succession controlled by such clocking device.

A preferred embodiment of the invention wherein the switching is accomplished by semiconductor elements and the succession of the closing and opening operations is conjointly determined by a clocking device and a logical network, is hereinafter described.

The clocking device and the logical network are included in the control device indicated by the numeral **20** in FIG. 3. It will not be herein described because the different means of achieving the same are known to anyone skilled in the technique of electronics, and may be easily deducted by the sequence of command signals that the said control device is called upon to deliver to the switching elements of the circuit, dependent upon the input data furnished by the measuring devices.

In this embodiment of the invention the switches are conveniently constituted of solid state switching elements, such as diodes, silicon controlled diodes, transistors and the like.

FIG. 3 represents the circuit diagram of a circuit using transistors as switches, which circuit is particularly adapted for use with output voltage which is generally higher than the input voltage.

This converter circuit includes a non-stabilizer current source **21** having one terminal connected to ground and the other terminal connected to the inductor **22**, a PNP-type transistor **23**, whose emitter and collector are respectively connected to terminals **33** and **32** of the inductor, and whose base is connected to the emitter through resistor **24** and is also connected to terminal **37** of the control device **20**. A command circuit, not shown, is part of the control device and connected to said terminal **37** may turn said transistor on or off, fulfilling the function of switch **5** of FIG. 1.

Terminal **33** is also connected to the emitter of transistor **25**, whose collector is connected to ground though low value resistor **31**. Point **40**, common to resistor **31** and collector of transistor **25**, is connected to terminal **35** of the control device **20**. The base of transistor **25**, connected to the collector through resistor **26**, is also connected to terminal **36** of the control device.

A command circuit, not shown, is part of the control device **20** and connected to the terminal **36**, may turn said transistor **25** on and off, fulfilling the function of switch **7** of FIG. 1. When this transistor is conducting, it completes the circuit consisting of power supply **21**, inductor **22**, transistor **25**, resistor **31** and ground.

In the foregoing circuit a current flows, and point **40** is brought to a voltage, relative to ground, proportional to said current. The resistor **31** therefore fulfills the function of the current measuring device **4** of FIG. 1, differing that it is series connected to the inductor only when the terminal **33** is connected to the ground. This disposition has the advantage that, when the inductor is short-circuited by transistor **23**, the resistance **31** is not included therein.

Terminal **33** is moreover connected to the emitter of the transistor **27**, whose collector is connected to output terminal **34**. The base of said transistor **27** is connected to its emitter through resistor **28**, and furthermore to terminal **38** of the control device **20**. A command circiut, not shown, contained in said control circuit and connected to said terminal **38** may turn the transistor **27** on and off.

The transistor **27** therefore fulfills the function of switch **8** of FIG. 1. The load **30** and the capacitor **29** are connected to terminal **34**, which is also connected to terminal **39**, as input to the voltage measuring device included in control device **20**.

The operation of the circuit, as controlled by the different command signals emitted by the control circuit **20** in dependence of input data, is hereinafter described, with reference to the diagrams of FIG. 4. The current I flowing through the inductor is represented by diagram *a*. Diagram *b* represents the voltage V_u. The diagrams *c*, *d* and *e* represent the ON and OFF conditions of the transistors **25**, **23** and **27**, the line drawn at level **1** means that during the corresponding time interval the transistor is ON, and the line at level O means the transistor is OFF.

The pattern of operation comprises repetitive operating cycles having a constant period T. Each period is divided into two sub-periods T_1 and T_2. The current I flowing into the inductor is controlled in one of said sub-periods, for instance T_1 and the output voltage V_u is controlled in the sub-period T_2.

At time t_0 sub-period T_1 is initiated. The control device applies a command to transistor **25** turning it ON and completing the circuit comprising the non-stabilized power supply **21**, inductor **22** and resistor **31**. It is assumed that at time t_0 the value of the current flowing in the inductor is lower than a prefixed value I_1. As a consequence the voltage at terminal **35** is also lower than a given value, and in this condition the control unit maintains the transistor **25** in an ON state. The current in the said circuit increases according to the time constant of the circuit, and it may be assumed to increase linearly following the line AB, as the sub-period duration is assumed to be small with respect to said time constant. At instant t_1, the current reaches the limit value I_1 and as a consequence, the control device turns the transistor **23** ON and the transistor **25** OFF. Now the current flows in the circuit including only inductor **22** and transistor **23**, having a very high time constant. The value of the current will decrease according to the line BC at a very slow rate until the end of the of the sub-period T_1.

If at time t_0 current I is higher than the limit value I_1, transistor **25** is immediately turned OFF and the transistor **25** is immediately turned OFF and the transistor **23** is immediately turned ON.

From time t_2 on, that is, during the sub-period T_2 the circuit operation is controlled only by the value of the output voltage V_u at terminal **39**.

During the sub-period T_1 the capacitor **29** was discharged through the load **30**, and therefore it may be assumed that at time t_2 the output voltage V_u is lower than a predetermined lower limit V_2. In this condition the control device **20** turns the transistor **27** ON and the transistor **23** OFF completing the circuit comprising the power source **21**, inductor **22**, transistor **27** and the load **30**. The current, as heretofore shown, also continues to flow from the power supply **21** to the load **30** in the event the output voltage V_u is higher than the input voltage V_i. Therefore the voltage V_u increases along the line C'D', while the current decreases along the line CD. When the voltage V_u reaches the upper limit V_1, the control device turns transistor **23** ON and transistor **27** OFF. The current flows in the circuit comprising only inductor **22** and transistor **23** and varies according the line DE, while the voltage decreases following the line D'E'.

At time t_4 the voltage V_u reaches a predetermined lower limit V_2, the control device turns transistor **27** ON and transistor **23** OFF, the voltage increases along the line E'F', while the current decreases along the line EF. During all the remaining interval of sub-period T_2 the voltage V_u is maintained between limits V_1 and V_2, and the current decreases following the line CDEFG. At time T_6 the sub-period T_2 is terminated, and sub-period T_1 again starts, and the current first increases, and afterward decreases, while the voltage steadily decreases.

The voltage regulation therefore is not confined between limits V_1 and V_2, but between the larger limits V_1 and V_3, wherein V_3 is the voltage reached at the end of sub-period T_1. By a proper proportioning of capacitor **29** the minimum value V_3 may be maintained sufficiently close to V_1.

Several modifications to such operating pattern may be introduced for example, the duration of sub-periods T_1 and T_2 may change reciprocally. This happens for instance, if time t_1, when the transistor **23** is turned OFF, is taken as the initial time of the second sub-period, in

place of the fixed time t_2. The variation of the voltage and the current is then represented by the dashed lines respectively BHLMNOPQ and B'H'L'M'N'O'P'Q' of FIG. 4. To obtain this, it is sufficient that the joint control of transistors **23** and **27** be controlled by the voltage V_u immediately after the transistor **25** is turned off and transistor **23** is turned on.

The current and voltage measuring devices, which are patr of the control device **20** and have input terminals **35** and **39**, may be provided with adjusting inputs (not shown), capable of changing the limiting values I_1, V_1 and V_2 by means known to anyone skilled in the art. Therefore high operating flexibility may be obtained. In particular, if the upper and lower limits V_1 and V_2 of voltage V_u are made to change in the same sense and by the same value, either by manual control or by programmed variation, a device is obtained, which is able to deliver direct-current at a voltage continuously variable between large limits, either at the will of the operator, or according to a predetermined program.

In the frequent case, wherein the converter is called upon to deliver several different direct current voltages regulated at different levels, and fed by a single direct-current supply, the circuit of FIG. 5 may be applied. A common feeding device **77** comprises the non-regulated power supply **1**, the inductor **3**, the current measuring device **4** and the controlled switches **5** and **7** in a circuit corresponding to the circuit of FIG. 1. The current measuring device may be connected between switch **7** and ground, according to the circuit of FIG. 3. The conductors for the control of switches **5** and **6** and the output of the current measuring device **4** are connected respectively to terminals **79**, **80**, **81** of the control device **78**.

The output terminal of the common feeding device is connected to the inputs of n switches 8_1, 8_2 . . . 8_n, which may feed n loads 11_1, 11_2 . . . 11_n, connected in parallel with a respective one of n capacitors 10_1, 10_2 . . . 10_n. The control wires of the n switches 8_1 . . . 8_n are connected to corresponding terminals 83_1 . . . 83_n of the control device **18**, and the voltages present at the load inputs are similarly connected to terminals 84_1 . . . 84_n of said control device. This control device provides means, with reference to the different required values of the several output voltages, for selectively and sequentially feeding the different loads, by closing the corresponding switches **8**, and in addition it provides for periodically closing switch **5** or switch **7** in conformity with the regulation requirements for the current flowing in the inductor **3**.

The circuit diagram of FIG. 1 and the corresponding circuit diagram of FIG. 3 are particularly useful when the input D-C voltage is converted to a higher value, that is, if output voltage V_u is higher usually than the input voltage V_i. If this condition is not fulfilled, that is, if the output voltage is generally lower than the input voltage, for a long time interval, it is possible that the current I flowing in the inductor will be increased over the limit I_D (FIG. 2*a*) compatible with the proportioning of the components used. If the device is to be operated under such conditions, it may be convenient to add, in the circuit diagram of FIG. 1, two switches **70** and **71**, as indicated in FIG. 6. Switch **70** is series connected between positive terminal of the power supply **1** and the input terminal **2** of inductor **3**, whereas switch **71** is connected between said terminal and the ground. Both switches are controlled by the control device **19** by means of wires connected respectively to terminals **72** and **73** of said device. If, during the time when the switch **8** is closed, the current in the inductor **3** increases over a predetermined limit, switch **70** is closed and switch **71** is opened.

The following circuit is then completed, ground, switch **71**, inductor **3**, current measuring device **4**, switch **8**, load **11** and ground. In this circuit the E.M.F. due to the self-inductance of the inductor **3** is opposed by the entire voltage V_u. Therefore, the current will flow, charging capacitor **10** and increasing the output voltage V_u as required by the control device, but the value of said current will rapidly decrease so that it returns soon within admissible limits. When the current is decreased under the lower limit I_B (FIG. 2*a*) switch **71** is opened and switch **70** is closed, restoring the condition shown by the circuit of FIG. 1.

In the event the voltage conversion always takes place from a lower to a higher value, the device of FIG. 1 may be simplified, by substituting a diode for switch **7**.

In the embodiment of the invention corresponding to FIG. 3 this may be carried on by substituting a diode **75** for transistor **27** as shown in FIG. 7. As a consequence, the control device will not require the output terminal **38**.

The operation is as follows:

During the first sub-period T_1 the operation is the same as described with reference to FIG. 5. The output voltage V_u is constantly higher than the voltage of terminal **33** because, when the transistor **25** is ON, its voltage is near the ground voltage; and when the transistor **23** is OFF, its voltage is slightly lower than the voltage V_i. Diode **75** therefore is always backward biased and does not conduct. At time t_2, if the voltage V_u is lower than the lower limit V_2, a blocking signal is sent to transistor **25** which is turned OFF. As the circuit including power supply **21**, inductor **22**, transistor **25**, resistor **31**, through which the current I was flowing, is interrupted, the self-inductance of inductor **22** causes the voltage of terminal **33** to increase almost instantaneously, till it becomes higher than the output voltage V_u. In this condition diode **75** conducts and the current I is reestablished through the circuit including power supply **21**, inductor **22**, diode **75**, load. The capacitor **10** is charged and voltage V_u increases correspondingly the voltage at terminal **33** increases and remains higher than voltage V_u by a quantity corresponding to the voltage drop across diode **75**.

When the voltage V_u becomes higher than the predetermined value V_1, a conduction signal is sent to transistor **23** which turns ON.

Inductor **22** is short-circuited by conducting transistor **23**, and the terminal **33** acquires substantially the voltage V_i. Diode **75** is backward biased and does not conduct.

Therefore, by controlling both transistors **23** and **25** the control of the conducting or non-conducting state of diode **75** is obtained, and said diode fulfills the functions of switch **8** of FIG. 1.

If the voltage conversion always takes place from a higher to a lower value, the circuit shown in FIG. 8 which is obtained from the one of FIG. 3 by substituting diode **76** for transistor **23** may be utilized. Correspondingly, the control device will lack the output **37**. The operation is as follows:

During the time intervals that either transistor **25** or transistor **27** shown in the circuit of FIG. 8 are ON, the current flows in the corresponding circuits and the voltage of terminals **33** is slightly higher than the ground potential or the output voltage V_u. In both cases the diode **76** is backward biased and does not conduct.

During the first sub-period, transistor **27** is permanently OFF and, at t_2, also transistor **25** is turned OFF, the current is interrupted, and the voltage at terminal **33** increases almost instantaneously till it becomes higher than input voltage V_i. Diode **76** is properly biased to conduct and short-circuits inductor **22**.

The same happens during the second sub-period when, transistor **25** is OFF, and transistor **27** turns OFF. Therefore, by the control of transistors **23** and **25**, the control of the conducting and non-state of diode **76** is obtained and diode **75** fulfills the function of switch **5** of FIG. 1.

It should be understood that changes and modifications in the form, construction, arrangement and combination of parts, and sequence of operations, may be made and substituted in place of these herein shown, without de-

parting from the principle and scope of the inventions. In particular a substantial improvement in efficiency and power handling capability of the apparatus may be obtained by using superconducting materials in proper environment conditions for the construction of the induction.

What I claim is:

1. A voltage converter, including an input circuit having a first input terminal and a second input terminal and an output circuit having a first output terminal and a second output terminal; an inductive device and a first switch in a first circuit serially connected between said first input terminal and said first output terminal, circuit means connecting said second input terminal and said second output terminal to form a common terminal; current sensing means; voltage sensing means and a capacitor in parallel between said output terminals; said current sensing means and said voltage sensing means generating signals corresponding to the respective amplitudes of current and voltage sensed; a second switch in a second circuit with said common terminal and a portion of said first serially connected circuit, including said inductive device and said first input terminal, said second circuit comprising said current sensing means; a third switch in parallel with said portion of said first serially connected circuit comprising said inductive device; and switch control means being in circuit to receive signals from said current sensing means and said voltage sensing means and to actuate said first, second and third switches responsive to said signals to maintain the voltage at said output within predetermined limits when a load is connected between said output terminals and a voltage source is connected to said input terminals.

2. A voltage converter as defined in claim 1 wherein said first, second, and third switches each comprise solid state switching elements.

3. A voltage converter as defined in claim 1 wherein said switch control means effects operation of said first, second and third switches at selectively interlaced different time intervals.

4. A voltage converter as defined in claim 1, wherein said current sensing means is serially connected between said common terminal and said second switch.

5. A voltage converter, including an input circuit having a first input terminal and a second input terminal and an output circuit having a first output terminal and a second output terminal; and inductive device, current sensing means and uni-directional conductive device in circuit serially between said first input terminal and said first output terminal, circuit means connecting said second input terminal and said second output terminal to form a common terminal; said current sensing means and said voltage sensing means generating signals corresponding to the respective amplitudes of current and voltage sensed; a first switch in circuit including said current sensing means, said inductive device and said first input terminal; a second switch in parallel with said serially connected inductive device and said current sensing means; and switch control means, said switch control means being in circuit to receive signals from said current sensing means and said voltage sensing means and to actuate said first and second switches responsive to said signals to maintain the voltage at said output within predetermined limits when a load is connected between said output terminals and a voltage source is connected to said input terminals.

6. A voltage converter as defined in claim 5 wherein said first and second switches each comprise solid state switching elements.

7. A voltage converter as defined in claim 5 wherein said switch control means effects operation of said first and second switches at selectively interlaced different time intervals.

8. A voltage converter as defined in claim 5, wherein said current sensing means is serially connected between said common terminal and said first switch.

9. A voltage converter, including an input circuit having a first input terminal and a second input terminal and an output circuit having a first output terminal and a second output terminal; an inductive device and a first switch in a first circuit serially connected between said first input terminal and said first output terminal, circuit means connecting said second input terminal and said first input terminal to form a common terminal; current sensing means; voltage sensing means and a capacitor in parallel between said output terminals; said current sensing means and said voltage sensing means generating signals corresponding to the respective amplitudes of current and voltage sensed; a second switch in a second circuit with said common terminal and a portion of said first serially connected circuit including said inductive device and said first input terminal, said second circuit comprising said current sensing means; a unidirectional conductive device in parallel with said portion of said first serially connected circuit, comprising said inductive device; and switch control means, being in circuit to receive signals from said current sensing means and said voltage sensing means and to actuate said first and second switches responsive to said signals to maintain the voltage at said output within predetermined limits when a load is connected between said output terminals and a voltage source is connected to said input terminals.

10. A voltage converter as defined in claim 9 wherein said first and second switches each comprise solid state switching elements.

11. A voltage converter as defined in claim 9 wherein said switch control means effects operation of said first and second switches at selectively interlaced different time intervals.

12. A voltage converter, as defined in claim 9, wherein said current sensing means is serially connected between said common terminal and said second switch.

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